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Capabilities of WFIRST-AFTA for Coronagraphic Imaging of Exoplanets

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On the Shoulders of Giants: Planets Beyond the Reach of Kepler
Meeting-in-a-Meeting
AAS Meeting in Boston, MA
3-4 June 2014

Capability

- The coronagraph on WFIRST-AFTA will be able to:
  - Detect all known RV planets within its angular range
  - Characterize RV planets with photometry and spectroscopy
  - Discover nearby gas- and ice-giants
  - Detect zodiacal dust disks to a level of a few times our own
  - Demonstrate exoplanet direct-imaging technology in space

Constraints

- Not add requirements to spacecraft (pointing, etc.)
- Not contribute to critical path of mission
- Cost much less than dedicated mission
- Demonstrate direct-imaging technology in space
- Achieve compelling new science

Baseline Mission Science Requirements

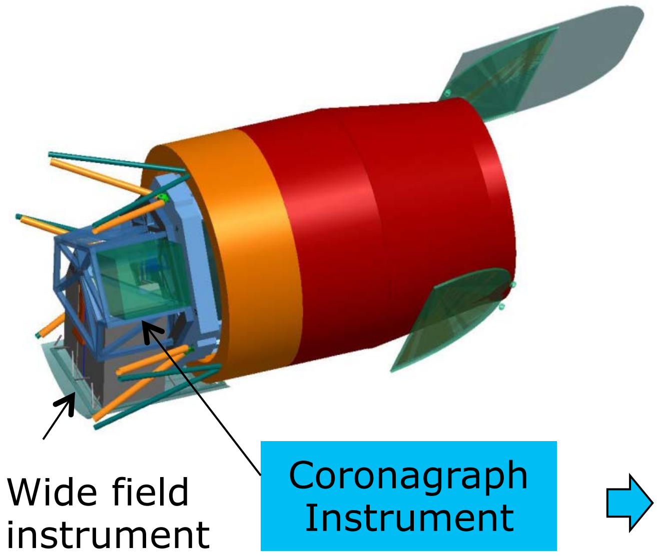
BSR6: WFIRST Coronagraph shall directly image exoplanets around nearby stars, and carry out color photometry measurements in the spectral range about 400-1000 nm, for planets as small as 4 Earth radii.

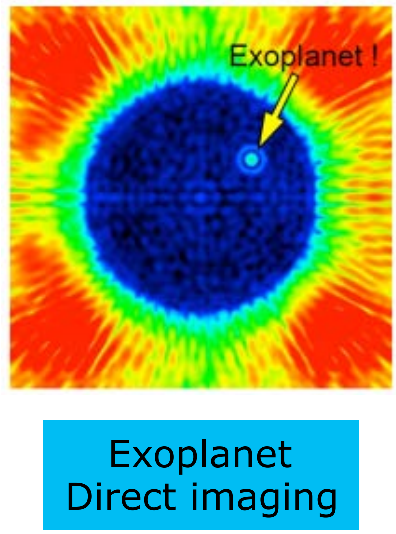
BSR7: WFIRST Coronagraph shall spectroscopically characterize planets by measuring continua and spectral absorption features over the wavelength range from about 600 – 950 nm with resolution about 70.

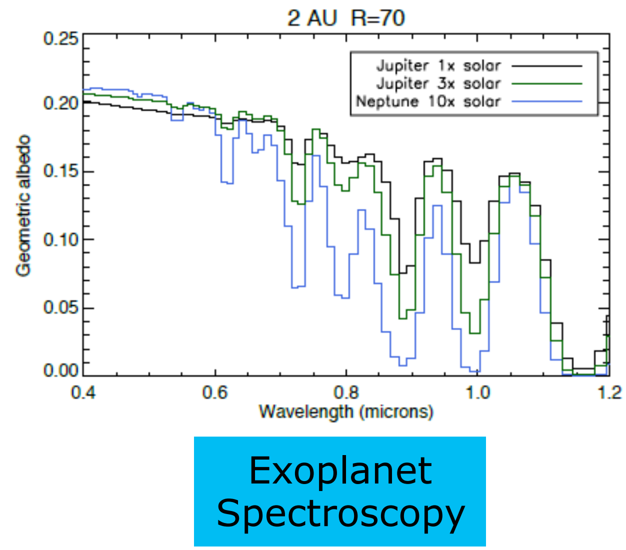
BSR8: WFIRST shall be capable of detecting a disk with 10 times our solar system's zodiacal flux in or near the habitable zone (~1 AU) of a solar-type star at a distance of 8 pc at 450 nm.

Ref.: Draft Program Plan (31 March)

AFTA Coronagraph Instrument







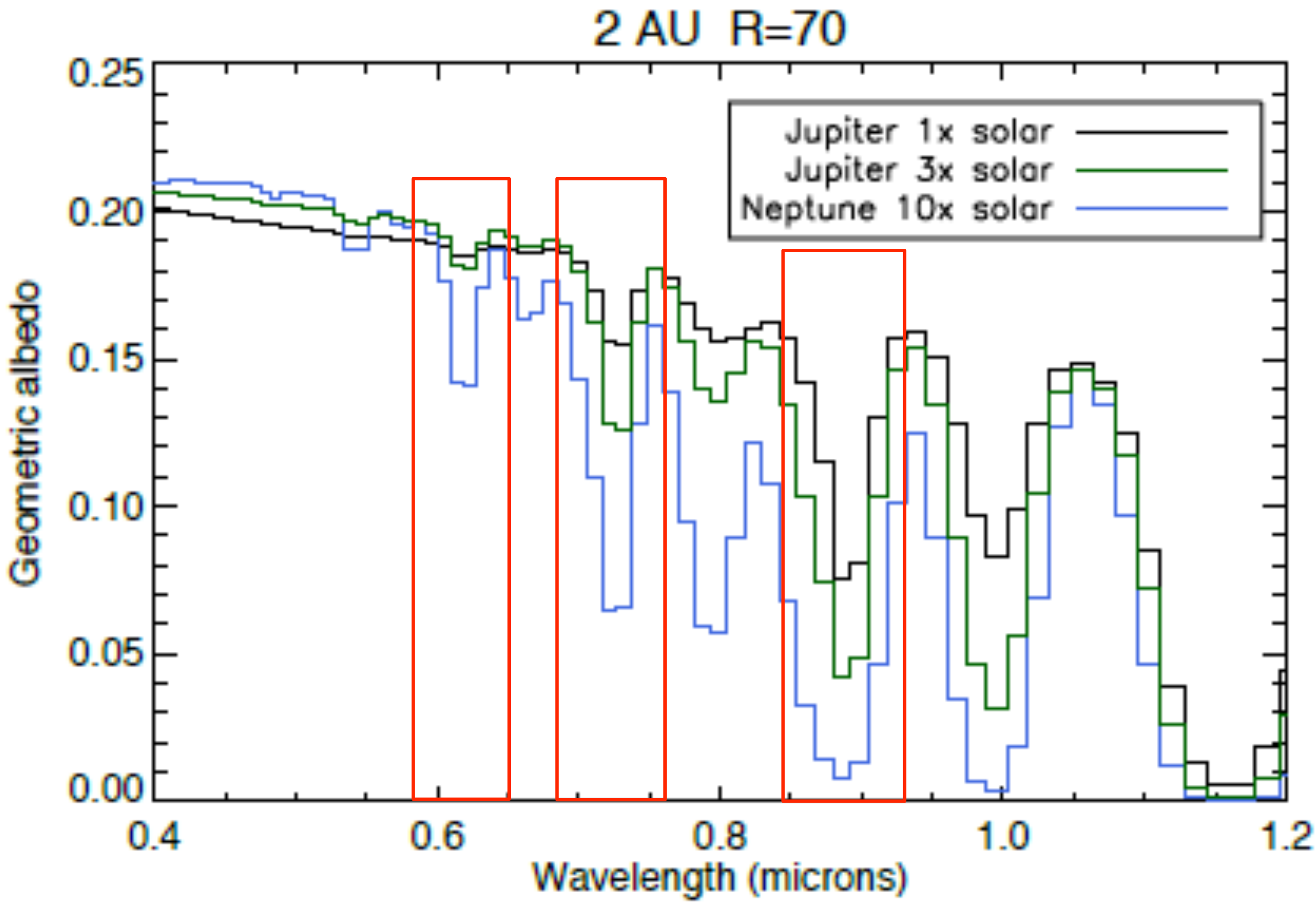
Bandpass	400-1000 nm	Measured sequentially in five bands, 10% each
Inner Working Angle	0.10 arcsec	At 400 nm, driven by challenging pupil
Outer Working Angle	0.80 arcsec	At 400 nm, driven by 48x48 DM
Detection Limit	Contrast = 10^{-9}	Cold Jupiters, not exo-Earths
Spectral Resolution	70	With IFS, from 600 to 1000 nm

Ref.: Feng Zhao, 13 Nov. 2013, revised

AFTA Coronagraph Instrument will:

- Characterize the spectra of over a dozen radial velocity planets.
- Discover and characterize up to a dozen more ice and gas giants.
- Provide crucial information on the physics of planetary atmospheres and clues to planet formation.
- Respond to decadal survey to mature coronagraph technologies, leading to first images of a nearby Earth.
- Image disks around nearby stars to ~ 10 zodi

Example spectra



Example 10% bands shown, centered on CH_4 features

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Neptune imaged on Gemini Planet Imager IFS

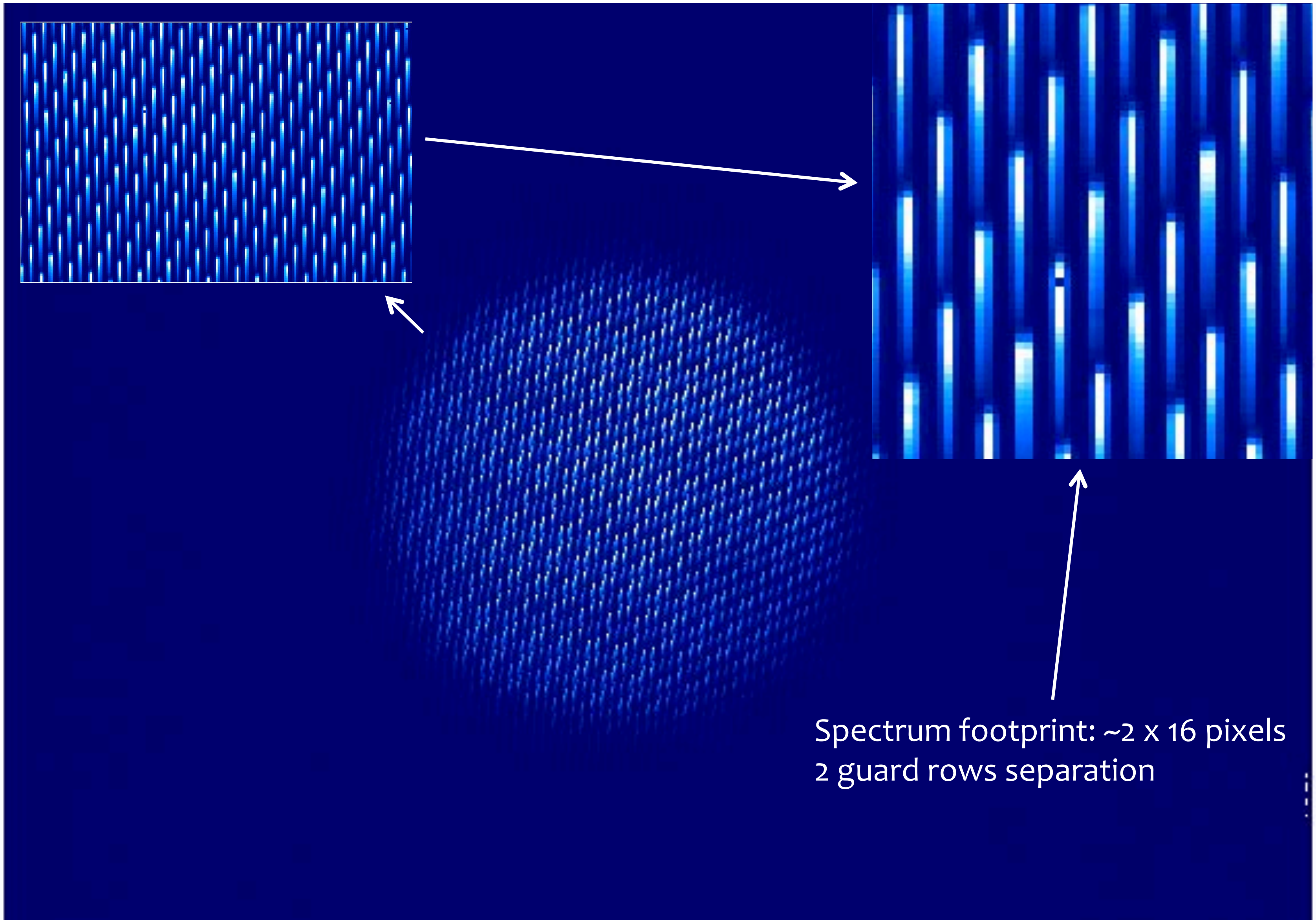
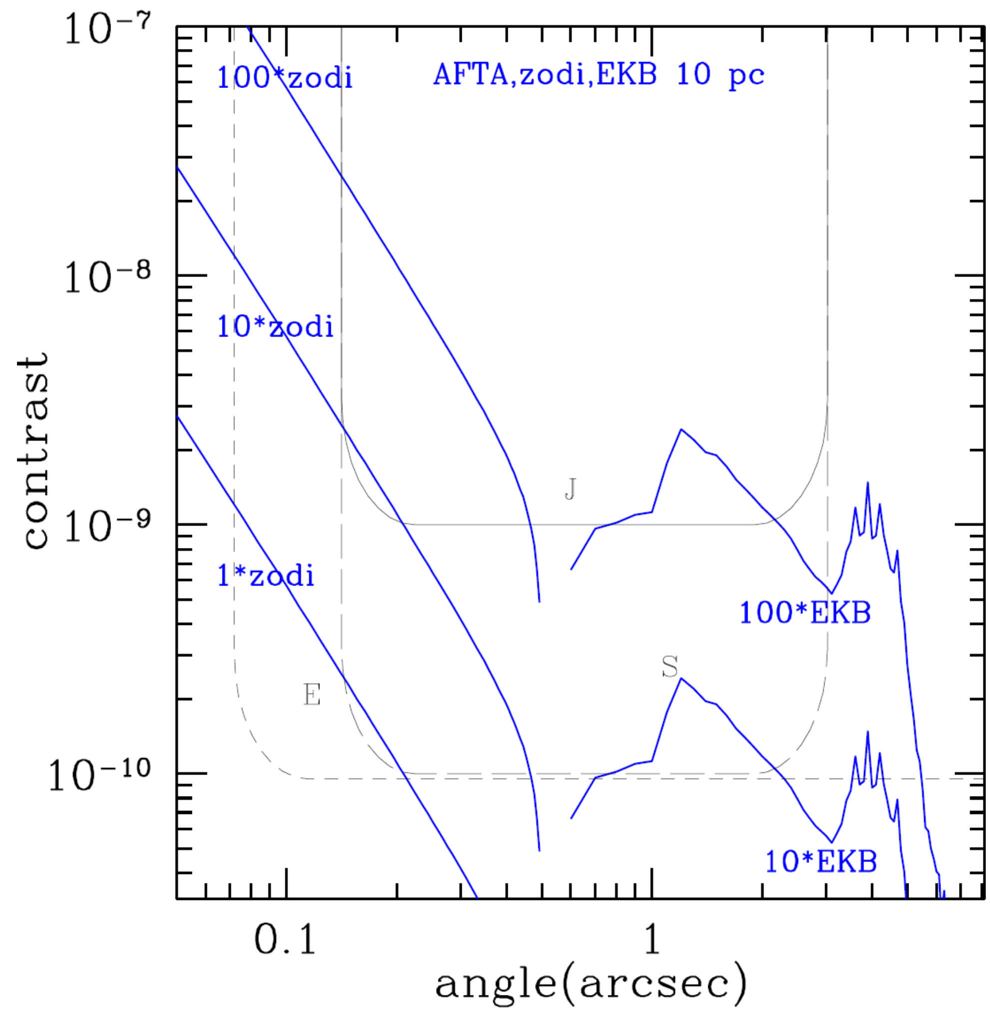


Image courtesy Bruce Macintosh

Zodi and Edgeworth-Kuiper



Apparent contrast (disc/star) of the resolved model zodi and EKB disks around the Sun at 10 pc, in scattered light (0.55 μm wavelength), per resolution element at the focus of the 2.4-m AFTA telescope. The inner and outer edges of the zodi are at 0.04 and 4.92 AU, corresponding to angles of 0.004 and 0.492 arcsec. The zodi model is from Kuchner (2006). The EKB curves are models of the Solar System's Edgeworth Kuiper Belt (Traub, 2013).

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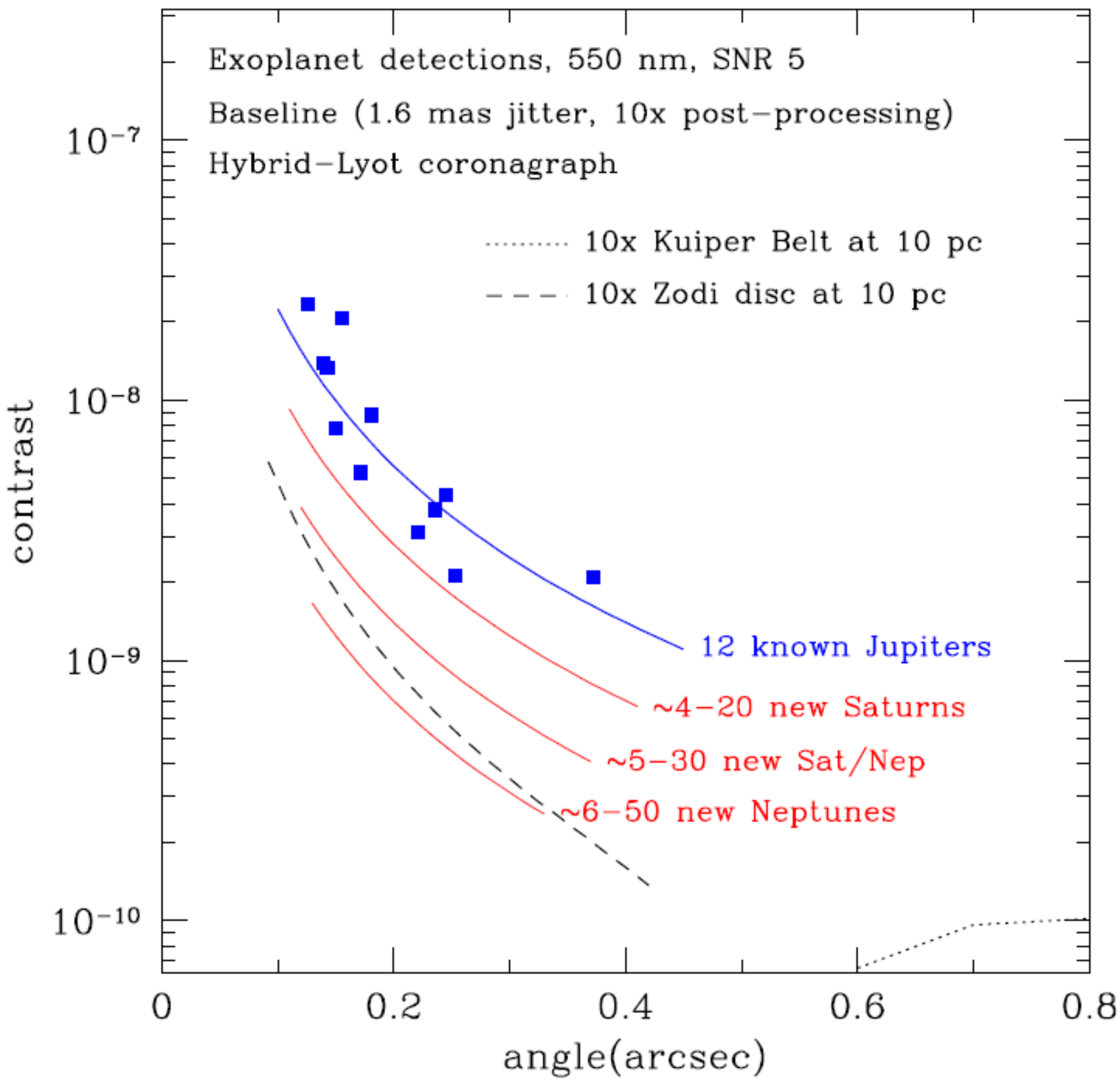
Planet yield: Known RV Jupiters & New Neptunes

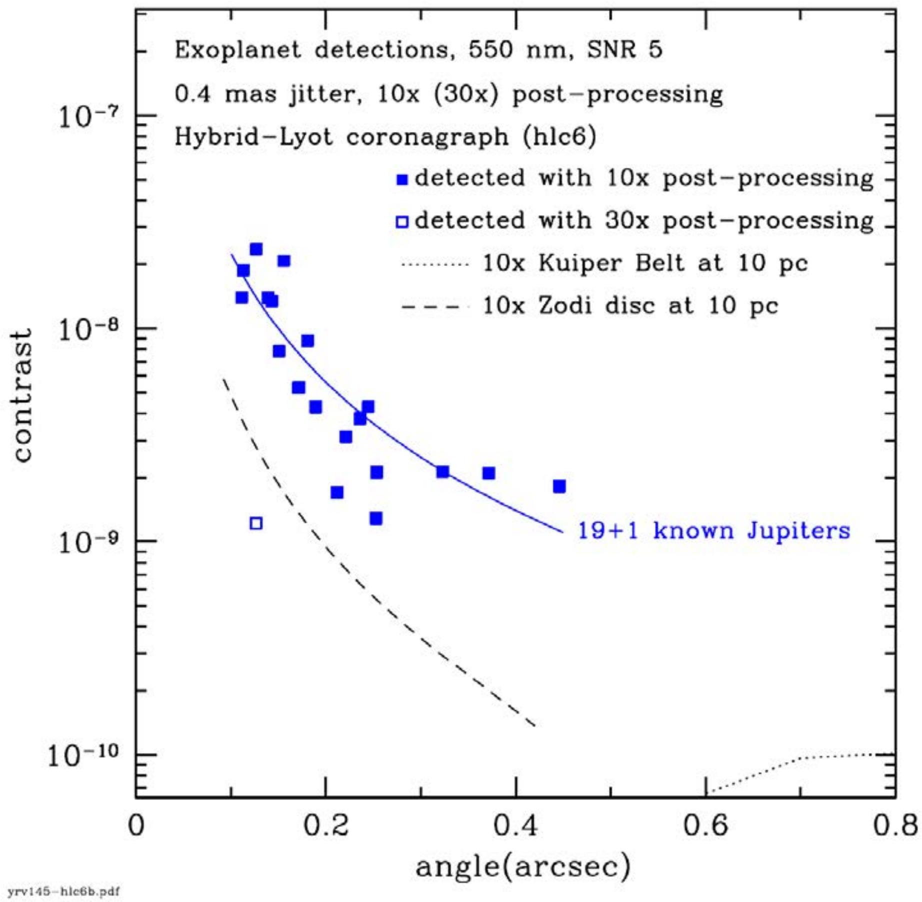


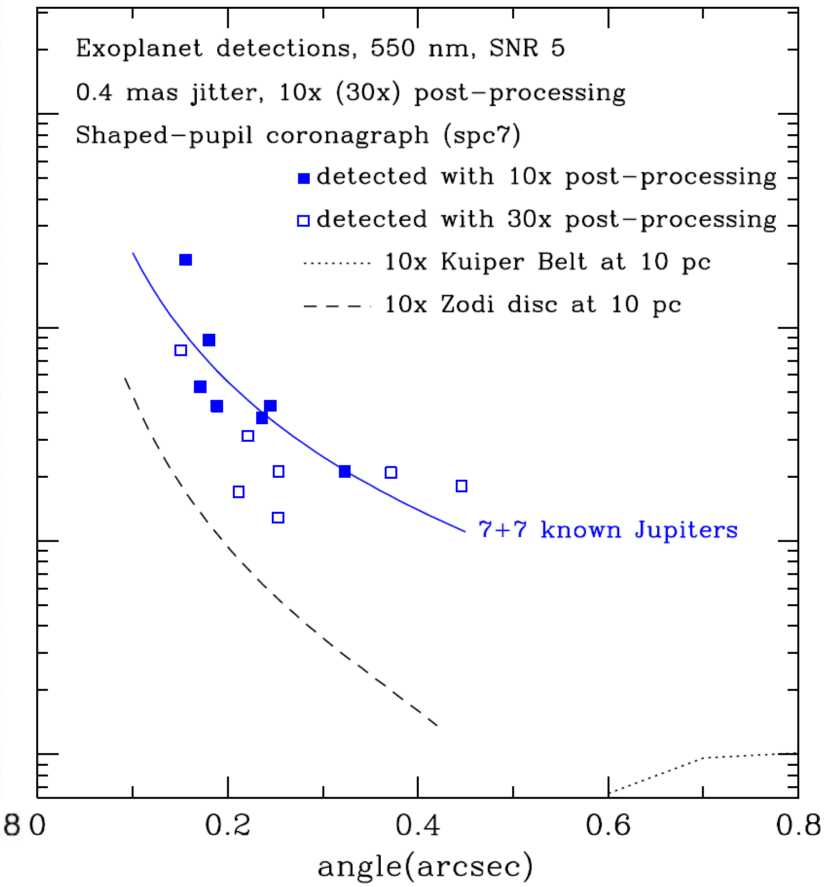
HLC design Dec. 2013
Baseline: 12 RV planets
Goal: 19

HLC design April 2014
Baseline: 20 RV planets
Goal: 21

Ref.: Interim Report, April 2014

RV planet yield with current OMC designs (May 2014)





HLC (20 May), unpolarized, 0.4mas jitter,
10x PPF gives 19 planets in 29 days
30x PPF gives 20 planets in 30 days

SPC (26 May), unpolarized, 0.4mas jitter,
10x PPF gives 7 planets in 7 days
30x PPF gives 14 planets in 22 days

Number of RV planets in less than 1 day each

No. RV planets in 1 day each, or less				
	0.4 mas, 10x PPF		0.4 mas, 30x PPF	
band	HLC	SPC	HLC	SPC
450	17	9	17	10
550	12	5	13	7
650	10	3	10	5
800	6	0	6	5
950	6	0	6	3

- Red band has fewer detections than blue, all cases.
- HLC typically has 2x more detections/day than SPC.
- HLC performs about the same for both cases of PPF, but SPC improves by several planets with 30x PPF.

Back-up charts

Pupil, ray trace

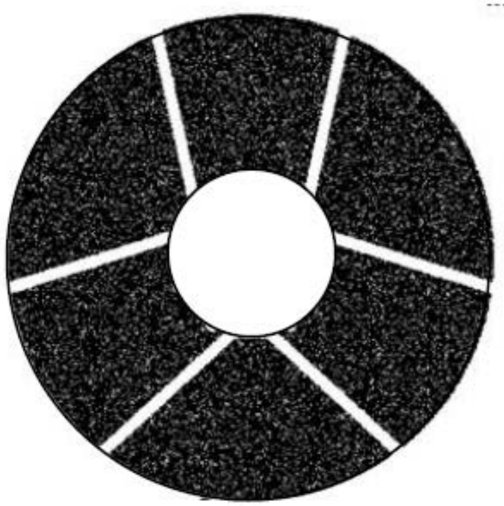


Figure 3-5: The telescope entrance pupil

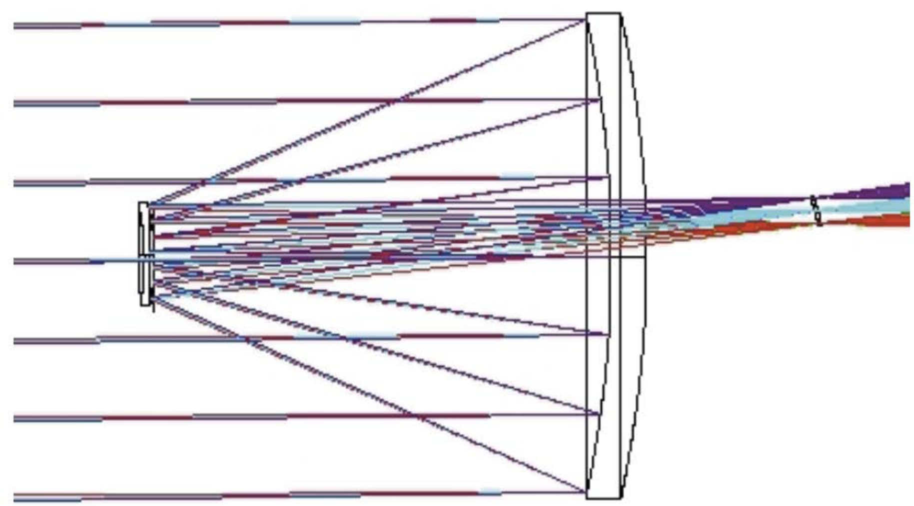


Figure 3-6: Ray trace through the telescope to the wide field channel intermediate focus.

Ref. Report, 23 May 2013

CH4 spectrum from Des Marais et al. 2002

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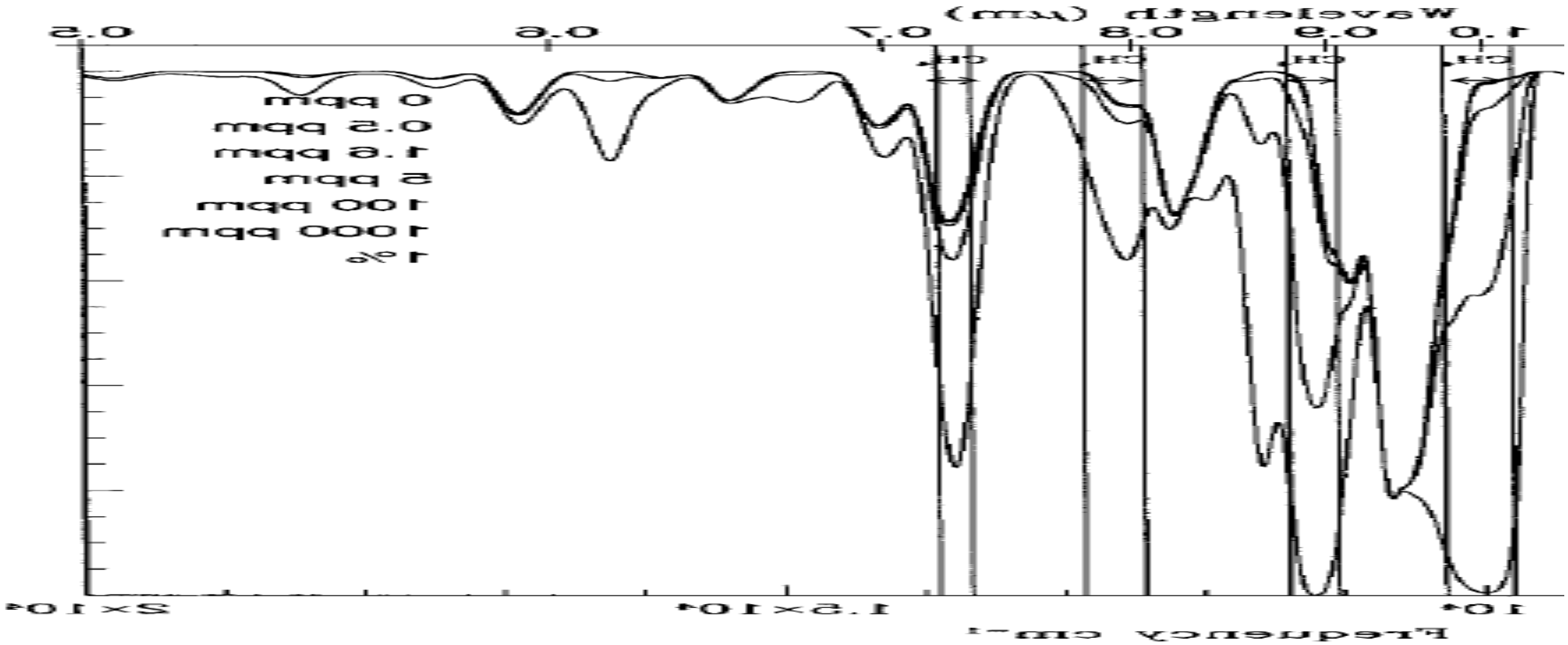

		σ (cm^{-1})				λ (μm)		
Band	*Species*	*Minimum*	*Maximum*	*Average*	*Resolution*	*Minimum*	*Maximum*	*Average*
28	CH_4	4,040	4,570	4,305	8	2.19	2.48	2.32
29	CH_4	5,610	6,190	5,900	10	1.62	1.78	1.69
30	CH_4	9,790	10,280	10,035	20	0.97	1.02	1.00
31	CH_4	11,040	11,390	11,215	32	0.88	0.91	0.89
32	CH_4	12,420	12,850	12,635	29	0.78	0.81	0.79
33	CH_4	13,660	13,900	13,780	57	0.72	0.73	0.73

Requirements Definition Process

Simulations

Requirements Flow

- NWNH Decadal Survey
  - WFIRST-AFTA Science Definition Team Report
  - WFIRST-AFTA SDT Charter

NASA HQ Controlled

- Science Questions
- Science Objectives
- Science Requirements

Level 1 Program Requirements*

* Science Requirements for Baseline and Threshold Missions, typically set at the end of Phase A.

Project Controlled

Cosmological Sims

- Sky Survey Rqts

Image Processing Sims

- Mission Data Set Rqts

Design/Operational Sims

Sky Truth

- Observatory Design/Ops Concept

Level 2 Project Science and Mission Requirements*

* Key programmatic constraints (e.g. mission life, launch vehicle, budget, schedule, etc., as appropriate) must be provided

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The next Objective is motivated by our need to understand the structure, atmospheres, and evolution of a diverse set of exoplanets. This is an important step toward the larger goal of assessing the characteristics of Earth-like planets that may be later discovered in the habitable zones of nearby stars. It is unlikely that any such planets will have exactly the same size, mass, or atmosphere as our own Earth. A large sample of characterized systems with a range of properties will be necessary to understand which properties permit habitability and to properly interpret these discoveries.

The goal of the WFIRST exoplanet direct-imaging survey is to understand the compositions and atmospheric constituents of a variety of planets around nearby stars and to determine the properties of debris disks around nearby stars in order to understand how planets interact with these debris disks. To accomplish this goal, the direct-imaging survey seeks to characterize photometrically at least a dozen known radial velocity planets, of at least 4 Earth radii with minimum star-planet separations of TBD, characterize spectroscopically half of these, and search for other planets around nearby (~10 pc) stars. Additionally, WFIRST aims to search for low surface density circumstellar disks around several dozen nearby stars as well as image the inner regions of known bright disks. This direct imaging survey of planets orbiting nearby stellar systems offers a critical approach to studying the detailed properties of exoplanets complementary to the transit studies of the Kepler mission. First, as with microlensing, planets detected by direct imaging tend to be at longer orbital periods than those found by transits. Second, spectra of directly imaged planets provide powerful diagnostic information about the structure and composition of the atmospheres. Similarly, high-contrast imaging of debris disks around nearby stars will provide crucial insights into the processes governing planet formation. Broadband imaging of such disks will provide information on the amount, location, and composition of circumstellar dust.

Primary science objective 4 below supports the goal for the Exoplanet Direct Imaging program:

Objective 4: Discover new planets and disks around nearby stars and characterize these new and previously known planets and disks by means of high-contrast imaging and spectroscopy and develop coronagraph technology to enable this science and as an investment for future missions.